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Effect of Air Cleaning Technologies in Conjunction With the Use of Rotary Heat Exchangers in Residential Buildings

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Abstract

This study is part of a research project concerning the possibilities of applying efficient air cleaning technologies using rotary heat exchanger in residential buildings. The purpose of this project was to identify and adapt new air-cleaning technologies for implementation in HVAC systems with rotary air-to-air heat exchangers. For this purpose, a mechanical filter with low pressure drop and a 4 cm thick activated carbon filter were selected for testing in a laboratory environment. The measurements included testing of the filters, separately and combined, in a ductwork to study the efficiency of the filters. The removal efficiency of the mechanical filter for ultrafine particles was examined using burning candles as sources for emission of particles. The measurements in the duct showed that the efficiency of the particle filter ranged between approximately 50% and 80% and the pressure loss was approximately 5 Pascal at an airflow rate of 216 m^3/h. The air velocity through the filter was 0.49 m/s. Furthermore, the removal efficiency of the combined filter for 6 chemical substances were examined using Hexane, Butanol, 2-Ethylhexanol, Heptane, 2-Heptanone and Acetaldehyde as sources for emission of gases. The measurement results showed that the efficiency of the combined filters ranged between approximately 30% and 80% and the pressure loss was less than approximately 20 Pascal at an airflow rate of 250 m^3/h.

Keywords – Rotary heat exchanger, ultrafine particles, VOCs, filter efficiency

1. Introduction

There is a considerable amount of old residential buildings that need improvement in order to reduce energy consumption. Rotary air-to-air heat exchangers, which recover the heat of used air in order to warm up supplied air, are going to be installed in many of these buildings. There are also many new residential buildings, in particular in passive houses, where this solution is selected. Rotary heat exchangers have mostly been used in Norwegian, Finish and Lithuanian low-energy house projects. This solution benefits energy conservation. However, with rotary air-to-air heat exchangers there is a risk of undesirable cross leakage of gases and particles from the exhaust air to the inlet air. The installation of novel air-cleaning filters in the HVAC systems addresses this problem.

The hypothesis that formed the basis for this project was that current and future air cleaning technologies create an increased potential for improving the indoor environment and making more efficient use of energy.

Recent studies [1] showed that the filtration efficiency of ultrafine particles of an electrostatically charged filter ranges between 54% and 78% and that the pressure loss is approximately 5 Pascal.

It also must be noted that filtration of particles must be combined with filtration of gases in order to achieve a good indoor air quality. Activated carbon filters are shown to remove the VOCs (Volatile Organic Compounds) and SVOCs (Semi-Volatile Organic Compounds) [2, 3] efficiently. The filtration efficiency of activated carbon filter depends on several factors, among them in arbitrary order the type of pollutants, concentration of the pollutants, pressure, temperature, and humidity, pore structure, quantity of the active site, and characteristics of the adsorbent material.

Furthermore, the amount of activated carbon in the filter is significant for the effectiveness of the filter. It means that there is a correlation between the number of pores of carbon and the removal of gases, and in addition the activated carbon has to be changed before all of its pores are saturated [4].

However, a carbon filter does not effectively remove the lower molecular weight gases from the air such as formaldehyde, sulfur and nitrogen dioxide. It should also be noted that carbon filters are less effective in humid conditions where the air contains a large amount of water molecules [5].

In addition, it is important that an efficient particle filter always is included as a pre-filter when combined with a gas filter. The function of a particle filter in such case is to prevent accumulation of particles on the gas adsorption filter, which otherwise would impair the gas adsorption performance.

The purpose of this project was to identify and adapt new air-cleaning technologies i.e. particulate filters in combination with gas filter for implementation in HVAC systems with rotary heat exchangers.

2. Methods

Test of particle filter in a ductwork

Measurements were carried out on a particle filter mounted in a ventilation duct in order to evaluate the filtration efficiency at different concentrations of UFPs. The duct was connected to a room. The desired UFP concentrations, generated by one candle, were provided in the room and small fans ensured that the air was completely mixed. The particle concentrations were measured inside the duct upstream and downstream of the filter. The measurements were carried out at five different concentrations of UFPs, ranging from approx. 2,800 (UFP/cm^3) to 100,000 (UFP/cm^3) and with an airflow through the duct of 216 (m^3/h). During all the measurements, the concentration of UFPs was measured by means of NanoTracer PNT 1000 upstream and downstream of the filter. This instrument measures the number concentration of particles in the size range 10 nm to 300 nm. A scheme of the test set-up experiments is shown in Figure 1. The set-up consisted of a test room, a fan and the particle filter. The test of particle filter has been presented in [1].

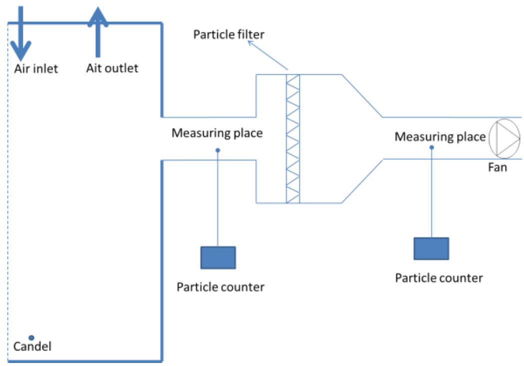

Fig. 1 A scheme of the test set-up for the experiment connected test room.

Test of activated carbon filter combined with a particle filter in a ductwork

In order to study the filtration efficiency of an activated carbon filter measurements were performed in a ventilation ductwork. The measurements included tests of a 4 cm thick activated carbon filter of filter class 20 PPI (pore per inch) with 1600 g/m^2 surface area in combination with the particle filter mentioned above.

The examined activated carbon filter has a total surface area of approximately 1,000 m^2 per gram. The substance used as a base material for producing the activated carbon was coconut shell. The surface area of the filter was 37x37 cm^2. The total airflow rate through the filter set-up was 216 m^3/h, which means that the contact time of the gas adsorption filter was 91 milliseconds.

The desired gas concentrations generated by 6 chemical substances were examined using Hexane, Butanol, 2-Ethylhexanol, Heptane, 2-Heptanone and Acetaldehyde as sources for emission of gases. These groups of chemical substances are common in non-industrial indoor air.

The concentrations of the gases were measured by means of Multi-Gas monitor, type 1302 from Brüel and Kjær. The instrument was calibrated against Toluene for the measurement of TVOC, and the concentration was stated as Toluene equivalents. Different chemical substances cannot be distinguished and besides pure hydrocarbons, the instrument also measures some other organic gases. The signal was designated TVOC (Total Volatile Organic compounds). The concentrations of TVOC were measured before and after the filters. The measurement points were approximately 50 cm downstream and upstream filters, respectively. The chemical substances were dosed separately.

A scheme of the test set-up for the experiments is illustrated in Figure 2. The set-up consisted of gas supply equipment and a filter set-up. The filter set-up consisted of a fan and a particle filter and a gas filter. The schematic diagram of the gas supply equipment is shown in Figure 2. A gas washing bottle with a liquid was placed in the air. An airflow rate of 0.072 m^3/h was passed through the bottle, which was connected to the filter set-up. The total airflow rate through the filter set-up was 216 m^3/h, which means that the contact time of the gas adsorption filter was 91 milliseconds. The measurement was carried out in a large test hall at the Department of Building Services Engineering, Gothenburg, Sweden. The relative humidity in the test hall was approximately 40% and the temperature was approximately 21 ^{0}C.

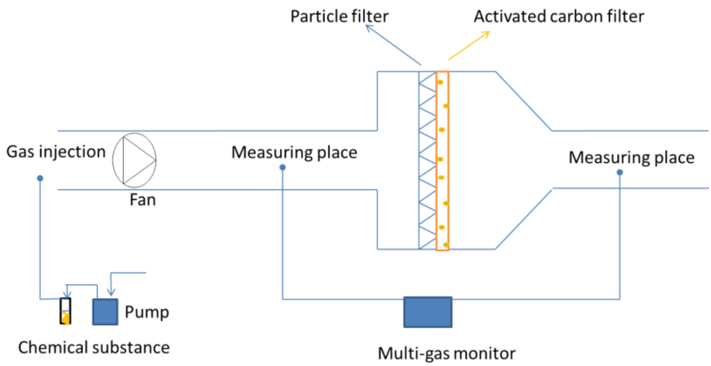

Fig. 2 A scheme of the test set-up for the experiment connected to a gas supply equipment.

Calculation of filtration rate of the activated carbon filter

The filtration efficiency values of the activated carbon filter were calculated according to equation 1:

$$\eta_g = [(C_{up} - C_{down}) / (C_{up} - C_b)] \times 100 \quad (1)$$

where

η_g = Filtration efficiency in %
C_b = Background concentration of a gas after the carbon filter (ppm)
C_{up} = Concentration of a gas before (upstream) the carbon filter (ppm)
C_{down} = Concentration of a gas after (downstream) the carbon filter (ppm)

3. Results

Filtration efficiency of particle filter

Figure 3 shows the filtration rate of the particle concentration generated by a candle in a room. The particle filter was an electrostatically charged filter. The measurements of the filter in the duct were made with five different particle concentrations. The aim of the study was to evaluate the filter performance at five different concentrations, while particles were being generated by a pure-wax candle. The results shown in Figure 3 were related to the duct measurement with an airflow of 216 (m^3/h). For this level of flow, the pressure difference before and after the filter was approximately 5 Pascal (Pa), which was measured by a manometer. This part of the study has been presented in [1].

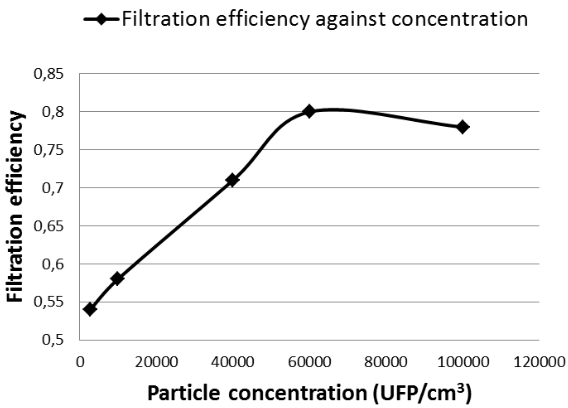

Fig. 3 Filtration efficiency against particle concentration [1].

Filtration efficiency of activated carbon filter combined with the particle filter

Figure 4 shows the filtration efficiency of the chemical substance concentrations by means of Multi-Gas monitors type 1302 from Brüel & Kjær. The results show that the activated carbon filter can efficiently reduce

Butanol, Heptane, 2-heptanone and Hexane. However, the efficiency of the filter is lower for 2-Ethylhexanol and Acetaldehyd.

In addition, the particle filter was separately exposed to Hexane concentration in order to study the efficiency of the particle filter against gases. The result showed that the particle filter has an efficiency of 2.7 % in removing Hexane concentration.

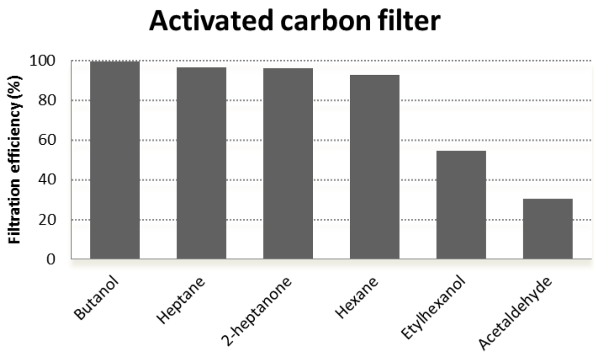

Fig. 4 Filtration efficiency against concentration of 6 chemical substances.

4. Discussion

Recent studies show that it is possible to find activated carbon filters which efficiently adsorb VOCs and also have low pressure drops [3]. Furthermore, another study [1] recently introduced a mechanical filter with low pressure drop. The authors reported that the efficiency of the filter ranged between 54% and 78% and that the pressure loss was approximately 5 Pascal. The air velocity through the filter was 0.49 m/s. It should be noted that the air velocity through the filter was lower than the air velocity through a similar filter in an air handling unit in a common building, which can be up to around 3 m/s. In general, increasing air velocity through an electrostatically charged filter will result in decreasing of the efficiency of filters.

The hypothesis behind the present study was that the examined particle filters used by [1] in combination with an activated carbon filter appears to be an ideal candidate to use for simultaneous VOC and particle filtration in HVAC systems which are equipped with rotary heat exchangers.

The activated carbon filter combined with the examined particle filter with low pressure drop was studied for 6 chemical substances that are typical indoor VOCs. With a contact time of 91 milliseconds, the measurements in the duct showed that the efficiency of the filter ranged between 30% and 78% and the pressure loss was less than approximately 20 Pascal at an airflow rate of 250 m^3/h.

Figure 5 illustrates pressure drop over the activated carbon filter combined with the particle filter and also separately over the particle filter.

The result shows that the relation between airflow rates and pressure drops is not linear. It means that the airflow through the filter is not laminar.

The pressure drop over the filters is low in comparison with the commercial filters commonly used in ventilation systems, which may have a pressure drop of 50 Pa.

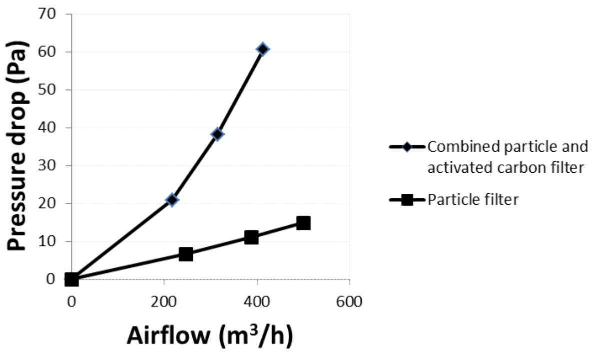

Fig. 5 Pressure drop over the activated carbon filter combined with the particle filter and also over the particle filter.

The presented results in this study show that the activated carbon filter as expected is able to remove Hexane, Butanol, Heptane, and 2-Heptanone. However, the activated carbon filter was not effective in removing Ethylhexanol and Acetaldehyde. In addition, periodical regeneration of activated carbon would allow the activated carbon filter to provide effective VOC air cleaning and thus allowing an efficient filter all the time [6, 3].

5. Conclussions

On the basis of the results, it is concluded that the combination of the two filters is a promising technology for removing particles and gases from extract air in HVAC systems. It may be particularly applicable with rotary air-to-air heat exchangers. On the other hand, further examinations of the filters are needed in order to study the properties of the filters when they are exposed to various kinds of indoor activities.

6. Acknowledgment

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